# Complexity is Free, but at What Cost?
## A Survey of the Current Uses of 3D Printers and the Ethical Concerns that Will Arise from Their Continued Use

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**Abstract.** As 3D printing becomes more widespread, ethical decisions must be made in regards to how the technology should be used. I discuss various ways 3D printers are currently being used, and how they may be used in the future. Three ethical concerns are addressed: 1) intellectual property rights, 2) the printing of plastic firearms, and 3) the printing of living body parts.

**Keywords:** 3D printing, additive manufacturing, bioprinting, printable guns

## 1 Introduction

3D printers have been around for nearly three decades, but they are mostly used for commercial manufacturing and were made available to consumers only in recent years. As the technology becomes more versatile and affordable, it is increasingly apparent that 3D printing will be the next invention to revolutionize societies and economies worldwide. 3D printers can create everything from customizable prosthetic limbs that fit better than generic models for a fraction of the cost, to lifelike action figures, to replacement parts for out of production items. Theorists predict that they could "revamp the economics of manufacturing and revive … industry as creativity and ingenuity replace labor costs as the main concern around a variety of goods" [1]. But with technology that promises more uses than can even be comprehended at this point, there are a lot of questions to be answered, such as whether 3D printers will positively or negatively affect society, and what limitations will or should be placed on their use.

This paper will first examine the promises of 3D printing technology to revolutionize the manufacturing industry and economy, and then address two ethical concerns that will come up as this technology advances: intellectual property infringement and the use of 3D printers to create ethically debatable items, such as body parts and firearms.

## 2 A Brief Background

3D printing is revolutionary because it combines computer-generated ideas with effective and easy manufacturing to create products previously thought impossible. To create with a 3D printer, the user starts with a Computer Aided Design (CAD) which is a digital model of the object. These can be made by creating the design through a CAD program or by using a 3D scanner to create a model of a real-life object [2]. The CAD software then slices the model into minute cross-sections that are fractions of a millimeter thick. The printer takes these cross-sections and applies them through a process called Additive Manufacturing (AM) in which each layer of material is deposited and fused with the layer below it [3]. Printers currently on the market are mostly restricted to printing with plastics, although larger industrial printers can work with metals. According to Hod Lipson of Cornell University, "any material you can squeeze, melt or generate into a powder, you can print" [4]. There are numerous unique variations on the typical plastic or metal printers:

- The "candyfab" uses granulated sugar to print candy [5].
- The "Burritob0t" can print customized burritos in less than five minutes [6].
- The "D-Shape" prints sandstone to create houses [7].
- Researchers have printers that use living cells to print "cartilage, meniscus of the knee … spinal disks and heart valves" [4].

One benefit to 3D printing is that it is more eco-friendly than traditional methods of manufacturing. AM is revolutionarily efficient, both in terms of environmental impact and production cost. First, AM requires as little as one-tenth the amount of material as conventional approaches. Whereas traditional manufacturing must remove excess, AM builds up materials until it forms a whole [8]. Second, taking the manufacturing out of the factory also means that objects can be created anywhere, thereby cutting down on shipping requirements. Third, producing only when required removes the need for an economic system based in mass production that leads to thousands of surplus products being wasted [4]. 3D printing is beneficial because it allows for manufacturing physical objects on-site with minimal waste.

The second benefit of 3D printing is cost-efficiency for individual businesses because it streamlines the production process. Wohlers Associates, a consulting company that pays special attention to 3D printers, estimates that businesses using these devices can reduce costs by 50% and time requirements by nearly 70% [9]. The driving factor behind the cost reduction is that "complexity is free" [4]. It used to be that fabricating businesses spent most of their time creating and re-creating prototypes, and the more complex an object the more time, personnel, and money it required. With 3D printing, the major expense for companies is now just the amount of material needed to build the object [10]. 3D printing also cuts out assembly lines because a 3D printer can print moving parts at the same time, already assembled [2]. Daniel O'Conners demonstrated this by printing "a spinning gyroscopic thingumabob complete with moving ball bearings" in one session which moved freely after being removed from the machine [11].

The ability to handle complexity leads to the third benefit: innovation. With 3D printers, manufacturers and even at-home amateurs can create structures that would be impossible with any other approach. For example, a 3D printer can create a complete

bike chain, printed with the links already connected. And with reduced barriers to participate in 3D manufacturing anyone with access to a printer can contribute [8]. This change has begun to bring about the democratization of manufacturing, which, as it continues, will "allow local entrepreneurs to solve all kinds of problems, both big and small" [12]. People will not have to rely on off-the-shelf products but will be able to customize existing items or create entirely new products to find more efficient solutions. The most important function of 3D printers is the fact that they allow an entirely fresh generation of ideas to come into being. In Lipson's words, "it's not about how you duplicate things that you make today with other techniques, but it's how you explore, as we said, the new frontiers of design, making things you can't imagine today" [4]. 3D printers are not simply going to change how products are made, but will widen the definition of what it is possible to make.

As with the arrival of any revolutionary technology, the changes that come about may be difficult to embrace at first. 3D printers will change the way we think about modern manufacturing practices, and as a result could render many of them obsolete. Businesses that rely on the current way of doing things – like assembly lines and mass production – may have a hard time keeping up, but eventually this revolution will bring about new opportunities. "As businesses, industries, and jobs go away, new ones appear, and historically the new ones more than make up for the old ones that have vanished" [5]. One possible outcome is the strengthening of small businesses. Currently, it is difficult for locally-owned shops to compete with mega-store corporations. Small businesses cannot stock the same variety of products or rely on a national or global infrastructure to get cheaply produced goods. But with 3D printing, creativity will quickly surpass mass productivity in economic importance. In terms of the effects 3D printers will have on businesses and the economy, the outlook is positive.

## 3 Intellectual Property Concerns

Because 3D printers are so efficient at production and reproduction, there are several ethical concerns that must be addressed in the upcoming years. The first is that of intellectual property. Like the printing press, photocopier, VCR, and DVR before it, the 3D printer will be the center of a debate between individuals protecting fair use and open sources, and companies protecting copyright and patents.

The 3D printer of today is comparable to the computer in its formative years: this technology has the potential to revolutionize the creation and distribution of physical objects just as computers revolutionized the creation and communication of ideas. However, the same pitfalls that the computer industry went through have the potential to affect the 3D printing industry before it really gets started. Michael Weinberg, an attorney for Public Knowledge, refers to laws like the Digital Millennium Copyright Act that restricted the rights of the general public on the internet before the general public even knew they had those rights. He says that unless people actively learn about and defend their rights to fair use and open source materials in regards to 3D printing, they may lose them as corporations and industries that feel threatened by innovative technology try to protect themselves by restricting usage. [2]

Just as with the computer industry, the rise of the 3D printer will most likely expand the manufacturing industry but there will be strife before this can happen because it goes against most of the prevalent business models. Entrepreneurs and hobbyists looking to make use of 3D printers will have to compete with established industries protecting their interests. Patent holders will try to put restrictions on CAD files to prevent users from either scanning and reproducing copyrighted products, or creating products that infringe upon established patents. Currently, there are multiple sites where users can freely share CAD files in peer-to-peer communities. If the files become legally restricted then these open source communities may be destroyed by those who assume that any CADs shared are pirated, in the same way that Napster and other peer-to-peer sites were taken down.

In his essay, "It Will Be Awesome If They Don't Screw It Up", Weinberg advises 3D manufacturers on how to practice their rights without infringing on copyrights, patents, or trademarks. The best way to keep 3D printing technology from being restricted is by knowing how to use it without violating intellectual property rights in the first place. However, it is still going to be difficult to maintain the right to freely create and share in the face of large industries that feel threatened. The fact that there is no way to prove the benefits 3D printing will have does not make this problem any easier, because "policymakers and judges will be asked to weigh current concrete losses against future benefits that will be hard to quantify and imagine" [2]. It is likely that this case will go the way of its predecessors, photocopiers and VCRs, and be settled in favor of the new technology, but given the counter-examples of the computer industry's heightened restrictions it would be prudent to be vigilant about the public's rights to fair use of products and open source sharing of creative material.

## 4 Issues Arising from Printed Weapons?

While the right to creation via 3D printing should be preserved, there are some scenarios in which advanced home manufacturing could cause a real danger to the public. One benefit to the current system of centralized manufacturing is that it can be regulated. Dangerous objects like firearms are supposed to be made and distributed only by certain people and only in accordance with specific guidelines. Decentralized 3D manufacturing can avoid these regulations entirely by allowing individuals to print their own weapons, or at least enough of the component parts to avoid regulation.

In the United States, there are currently several layers of law enforcement surrounding the creation, distribution, and purchase of firearms at both the state and federal level. Specifically, "anyone 'engaged in the business' of manufacturing, importing or dealing in firearms is required to become a federal firearm licensee" and when any gun is sold, the distributor must run a background check on the buyer and record the serial number of the gun which must be included by the manufacturer. However, once you go beyond that the regulations become more complicated. For example, since the component parts of guns can be sold separately, the piece that is legally considered the "firearm" is the central frame, also known as the lower receiver, because it allows for the combination of the other pieces. Additionally, there are restrictions about how a gun may be made or what materials must be used. For

example: “the Undetectable Firearm Act of 1988 requires that all major gun components generate accurate depictions in x-ray machines and also requires assembled firearms to trigger metal detectors”. In this way, the distribution of firearms is restricted by limiting who can buy or sell guns as well as by specifying how gun parts must be made and ways to track them. [3]

The current system of regulating gun access and use is not perfect, but 3D printing is poised to upset any efficacy of the regulations. This is in part because of two current trends: 3D printing is becoming more advanced and widely available, and the firearm industry is beginning to use more polymer materials in weapons design, specifically in the design of the frame – the one regulated component. While there are still metal components that would have to be purchased from an arms manufacturer, the frame could be printed at home without having to adhere to any regulations. Additionally, 3D printers soon will have the capability of printing the highly-regulated parts that can alter a semi-automatic rifle into a fully automatic one. These abilities to make alterations at home circumvent laws restricting the use of highly dangerous weapons by the public. [3]

Americans have never been explicitly prohibited from creating their own firearms, but historically being able to make these weapons required the dedication to learn metalworking first. Now 3D printers are making it so that “a person with little to no understanding of firearms will nonetheless be capable of wielding a weapon in [a] short matter of time” [13]. This year, the Texas-based group Defense Distributed, headed by Cody Wilson, successfully fired their 3D printed handgun, “The Liberator,” and put the CAD files online for others who have 3D printers to use. The gun is entirely plastic except for a firing pin and the ammunition – the plans do include a piece of steel that would set off metal detectors, but it is an enhancement that can be omitted without affecting the functionality [14].

This 3D printing innovation has set authorities scrambling to counteract the effect of do-it-yourself, undetectable firearms. New York Congressman Steve Israel called for the renewal of the Undetectable Firearms Act after hearing the news, while New York Senator Charles Schumer suggested banning 3D-printed guns entirely. The Australian police force released a statement warning people that using the Liberator would put their personal safety at risk, explaining that they had tested it and the gun exploded on the second round. Police Commissioner Andrew Scipione attributes the “catastrophic failure” to a lack of standards for homemade weapons that endanger the gun owners as much as their targets [15]. The general political tone seems to be leaning towards restriction, but in America at least, forbidding the personal production of weapons may be constitutionally impossible.

Although there is a legitimate threat to the public involved with this system of printing, any legal action in America restricting access to or use of 3D printers may go against the Constitutional right to bear arms. In fact, there is an argument that allowing 3D printed guns would actually enrich Second Amendment protections. Currently, the right to bear arms does not apply to those who are handicapped and cannot use generically-produced weapons to defend themselves. With infinitely customizable design options, 3D printers could extend this right by creating unique guns that compensate for the user’s limited abilities [3]. Additionally, the recent Supreme Court case of the District of Columbus v. Heller upheld firearm rights, and explained that the continued right to be able to resist tyranny is one of the key reasons

for upholding the Second Amendment even in the modern age. It is arguable that the "ability to make one's own weapons, spare parts and ammunition would be essential to sustain protracted resistance against tyranny or to obtain meaningful protection in times of anarchy" [3]. If this issue goes to court in the United States, it is reasonable to expect that this argument will be made and supported by those who view their right to bear arms as inalienable.

As with all technology, there are ways to use it for dangerous purposes, but that must be weighed against the improvements and greater rights that it provides as well. That being said, protecting lives should be held above protecting rights. Until firearm regulations and police enforcement are prepared to handle the possibility of homemade weaponry, these uses for 3D printers should be pursued carefully.

## 5 Printing the Biological World

Printed weapons are a concern that is being addressed currently, but there are benefits to looking ahead and giving consideration to applications of 3D printing technology that are not yet affecting mainstream culture. Researchers in the medical field are using printers in ways that will revolutionize health and wellness. So far, results are still experimental, but intentions and predictions for where this technology will go next range from improving the quality of life to altering the construction of the human body.

The 3D printing of biological material, or bioprinting, uses live cells and specially designed cultures as the "ink" in their printers. This field of study shares many of the same principles as AM, but has several differences and difficulties that come about from using living material. The first is that the cells settle and readjust after being printed. For this reason, a CAD made from a scanned organ cannot be printed as-is; "the organ blueprint must be larger and probably have a slightly different shape" due to "postprinting remodeling associated with tissue fusion, tissue compaction and tissue maturation processes" [16]. The second major difference is having to prevent damage from happening to the cells during and after the printing process. Vladimir Mironov, the director of the Advanced Tissue Biofabrication Center at the Medical University of South Carolina, explains, "[f]rom an engineering point of view, high temperature and toxicity (typical for rapid prototyping technologies and processes) are not acceptable for the bioprinting process" [17]. Every step of the process of printing puts strain on the cells, from being stored in cartridges, to being ejected, to surviving in lab conditions afterwards.

Despite these complications, scientists have already had success with their bioprinting experiments:

- Laurence Bonasar of Cornell University used a modified Fab@Home printer to print cartilage directly onto a bone [17].
- A team of researchers, also using a Fab@Home 3D printer, used cartilage from calves and silver wire to print a pair of functioning bionic ears which continued to perform for more than ten weeks [18].
- The University of Bordeaux was the first to work on printing bone tissue [17].

- A group from the Wake Forest Institute for Regenerative Medicine successfully printed skin onto live animals and showed that the procedure cut the healing time of wounds by more than half [17].
- The research company Organovo printed a functioning, miniature human liver using a proprietary 3D printer, NovoGen [19].

Much of this bioprinting is focused on one of two goals: printing entire organs for transplant or printing functional tissue for medical research. Achieving the goal of printed organs will be very difficult, but steps are already being made. For example, Mironov and his co-authors state that the most challenging step is managing to print the system of arteries necessary for maintaining cell life [16], but Mironov himself goes on to claim in a later paper that several universities, including his own, have data to show that this is feasible [17]. Eventually scientists want to reach the point where they can collect a patient's cells and print a new organ directly into the body, which would have numerous benefits. Most notably, it would "once and forever eliminate patient waiting lists for organ transplantation," thus saving countless lives which would otherwise be lost simply due to lack of resources [16]. Additionally, being able to collect and print with the patient's own cells would eliminate the dangers of the body rejecting the new organ or developing tumors [17]. This achievement will allow for a higher quality of life for a greater number of people, without requiring sacrifice or endangering the patient unnecessarily.

Bioprinting tissue for medical research is likely to be happening sooner than made-to-order organs. It may not be as accurate as in-depth clinical trials with real patients, but it is expected to be "more predictable than small or even large animal testing" and simultaneously "reduce the costs of drug development and improve drug safety" [16, 17]. Overall, this will be a benefit to the medical community. Researchers will be able to have similarly if not more useful information from testing with human tissue, all without the ethical conundrum of weighing benefits against testing on sentient animals.

Since bioprinting is still in its formative years, there is a great deal of thought being put towards how it will be used in the future, and how it may even have an influential role in the shaping of the future. Mironov speculates that being able to make body parts to order with your own cells will lead to two outcomes: on one hand it can extend the length of human life as each part that wears out is replaced, and on the other hand it may create a culture of what he terms "body fashion" as people with the means to do so design and print custom body enhancements for themselves [17]. This one example demonstrates how a single piece of technology can have such far-reaching effects as to influence both the quality of life and changes in culture.

Along with expanding the length of our lives, bioprinting and 3D printing can help to expand the physical capabilities of humans. This invention could be what makes long-term space exploration possible: the ability to travel with a full hospital and manufacturing facility. If that does not sound enough like science fiction, there are some people who are interested in bioprinting for even more futuristic reasons. The group that created the bionic ears out of cartilage has explained that their goal is to develop "a unique way of attaining a seamless integration of electronics with tissues to generate 'off-the-shelf' cyborg organs" [18]. These possibilities are even spreading into the art world. Heather Dewey-Hagbog has created a work called "Stranger Visions" in which she collects discarded DNA from public places, analyzes the

samples, and then uses the genetic information to 3D print a face [20]. While these are not totally accurate resemblances – no one has recognized themselves in her work yet, at least – and she only prints in plastic, she believes that this is just a precursor to being able to clone a person from a bit of hair or skin. These predictions may seem like something from a strange tale, but researchers are working every day on turning them into reality.

## 6 Conclusion

3D printing is the next pivotal step in advancing technology, and will disrupt the established systems as thoroughly as the computer and the invention of the Internet did mere decades ago. 3D printing has the potential to greatly improve our quality of life and expand our ability to practice our inalienable rights. But, at the same time, there are dangers and new methods of misuse that must be anticipated and prevented. Despite the pitfalls that arise with any new piece of technology, 3D printers will benefit the quality of life. While precautions must be made to prevent dangerous and illegal use, they should not include restricting the distribution and creative freedom that will bring about innovative advancement. As enthusiasts start experimenting with strange and exciting new uses "the best improvements will spread fastest, in a process akin to Darwinian natural selection" [5]. For that reason, it is important to encourage a "diversity of approaches and strong competition among different approaches" in order to ensure superior results going forward [16]. The next several years will be crucial in the formation of 3D printing rights and restrictions, and hopefully lawmakers, industry leaders, and everyday users will work to create the most creatively supportive community possible and allow the new possibilities it opens up to develop.

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## References

1. Vance, Ashlee. "3-D Printing Spurs a Manufacturing Revolution." *The New York Times* 13 Sept. 2010: n. pag. Web. 10 Apr. 2013.
2. Weinberg, Michael. *It Will Be Awesome If They Don't Screw It Up. Www.publicknowledge.org*. Public Knowledge, Nov. 2010. Web. 12 Apr. 2013.
3. Jensen-Haxel, Peter. "3D Printers, Obsolete Firearm Supply Controls, and the Right to Build Self-Defense Weapons under Heller." *Golden Gate University Law Review* (2012): n. pag. *LexisNexis*. Web. 10 Apr. 2013.

4. Wohlers, Terry, Bre Pettis, and Hod Lipson. "Can 3D Printers Reshape the World?" Interview by Ira Flatow. *Science Friday*. NPR. 22 June 2012. Radio. Transcript.
5. Easton, Thomas A. "The 3D Trainwreck: How 3D Printing Will Shake Up Manufacturing." *Analog Science Fiction & Fact*.Nov. 2008. Web. 20 Jun. 2013.
6. Cheshire, Tom. "BurritoB0t: the 3D printer that creates Mexican snacks in five minutes." Wired.co.uk. 16 Aug. 2012. Web. 18 Jun. 2013.
7. Steadman, Ian. "The race to build the first 3D-printed building." Wired.co.uk. 4 Jun. 2013. Web. 21 Jun. 2013.
8. "Print Me a Stradivarius." *The Economist* 10 Feb. 2011: n. pag. *The Economist*. Web. 15 Apr. 2013.
9. Quittner, Jeremy. "How 3D Printing Is Saving This Jewelry Design Business." *Crain's New York Business*. N.p., 20 Oct. 2010. Web. 15 Apr. 2013.
10. Graham-Rowe, Duncan. "3-D Printing for the Masses." *MIT Technology Review* (n.d.): n. pag. 31 July 2008. Web. 12 Apr. 2013.
11. O'Connor, Daniel. "Thingi Thursday: Spinning Gyroscope." Weblog post. *Www.prsnlz.me*. N.p., 13 Jun. 2013. Web. 16 Jun. 2013. http://www.prsnlz.me/blogs/daniel-oconnors-blog/thingi-thursday-spinning-gyroscope/.
12. MacDonald, Chris. "3D Printing and the Ethics of Value Creation." Web log post. *The Business Ethics Blog*. N.p., 1 Dec. 2012. Web. 10 Apr. 2013.
13. O'Neill, Kevin J. *Is Technology Outmoding Traditional Firearms Regulation? 3-D Printing, State Security, and the Need for Regulatory Foresight in Gun Policy*. *Social Science Research Network*. N.p., 3 May 2012. Web. 16 Apr. 2013. <http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2186936>.
14. Greenberg, Andy. "Meet The 'Liberator': Test-Firing The World's First Fully 3D-Printed Gun." *Forbes*. N.p., 5 May 2013. Web. 28 June 2013.
15. Clark, Liat. "Australian Police: Exploding 3D Printed Gun Will Kill You and Your Victim." *Wired.co.uk*. Wired, 24 May 2013. Web. 25 June 2013.
16. Mironov, Vladimir, Vladimir Kasyanov, Christopher Drake, and Roger R. Markwald. "Organ Printing: Promises and Challenges." *Regenerative Medicine* 3.1 (2008): 93-103. Web. 25 Jun 2013.
17. Mironov, Vladimir. "The Future of Medicine: Are Custom-Printed Organs on the Horizon?" *The Futurist* 45.1 (2011): 21-24. *Proquest*. Web. 25 June 2013.
18. Mannoor, Manu S., Ziwen Jiang, Teena James, Yong Lin Kong, Karen A. Malatesta, Winston O. Soboveio, Naveen Verma, David H. Gracias, and Michael C. McAlpine. "3D Printed Bionic Ears." *Nano Letters* (2013): 2634-639. *Pubs.acs.org*. 1 May 2013. Web. 27 June 2013.
19. Organovo. *Organovo Describes First Fully Cellular 3D Bioprinted Liver Tissue*. *Ir.organovo.com*. N.p., 22 Apr. 2013. Web. 27 June 2013.
20. Dewey-Hagborg, Heather. *Stranger Vision*. N.p., 7 Mar. 2013. Web. 24 June 2013. <http://deweyhagborg.com/strangervisions>.